Jess+: AI and Robotics with Inclusive Music-Making

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This paper discusses the findings from a cross-sector research project investigating how a digital score created using AI and robotics might stimulate new creative opportunities and relationships within the practices of an inclusive music ensemble. Through the concept of a digital score [65], AI and a robotic arm were introduced into an ensemble's musical practice to evaluate the impact and benefits of using autonomous systems to challenge barriers around a disabled musician's access to creative music-making. Throughout the development process we placed an emphasis on involvement and togetherness of not only the AI and robots' contribution to shared creativity amongst the ensemble, but also to the social aspects of the creative process across the team of musicians, developers, researchers and supporting organisations. The findings were surprising with many aspects of the project exceeding the expectations of the original aims. In short, all the musicians benefited from the introduction of these unfamiliar technologies with practices enhanced and relationships transformed.

CCS Concepts: • **Human-centered computing** → **Collaborative and social computing devices**.

Additional Key Words and Phrases: Embodied AI, neural networks, robotics, music-making, creativity, digital score

1 INTRODUCTION

When Miles Davis said, "Play what you hear, not what you know" [6], he was referring to the role a musician's imagination has in an improvisation. Practice, learning, experience and talent are all factors that can contribute to a musician's imagination and to their contribution to improvisation. And this is no different if the musician is disabled or non-disabled: the musician's imagination will generate ideas. However, if a body cannot move as dexterously as Miles Davis' could, or someone's speech isn't as free flowing as Eminem's rap, then regardless of the vividness of these individuals' ability to imagine a music improvisation, there are significant barriers to their engagement of many types of music and processes of music creation.

Addressing these barriers to music making is a central concern for many music organisations within the United Kingdom. The two organisations at the centre of this project for example, Orchestras Live (a national producer creating inspiring orchestral experiences for communities across England) and Sinfonia Viva (a British orchestra based in Derby, England) have for many years been seeking new ways of addressing such barriers. For example, Orchestras Live and Sinfonia Viva have supported and produced the *Able Orchestra* an "inclusive ensemble of disabled and non-disabled musicians. It is an evolving project based on the principle of enabling people to create and perform music on equal terms, regardless of their physical dexterity or musical experience."[1] Sinfonia Viva takes music into special educational needs schools and uses improvised methods to create a shared and inclusive musical experience for the students.

Both organizations are open to exploratory methods and novel tools and technology to promote inclusivity in music making. During an initial discussion between them and the authors of this paper, we introduced them to a

[1] https://www.inspireculture.org.uk/arts-culture/children-young-people/signature-projects/able-orchestra/

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research project of a creative-AI/robot arm digital score prototype that draws geometric markings in real-time that are reminiscent of experimental graphic score notations of the mid-twentieth century [24]. In response, Orchestras Live and Sinfonia Viva initiated a knowledge exchange collaboration with the authors about developing a project that could investigate the potential benefits of using this creative-AI and robotics to challenge barriers around a disabled musician's access to creative music-making. The focus of the conversation was on the types of new modes of music-making and the inclusive process of creativity.

In this paper we evaluate this cross-sector research project that investigated a novel integration of a creative-AI and robot arm –called *Jess+*– into the music making of an inclusive ensemble. The central research question at the heart of this investigation was:

> ***How does a digital score created using AI and robotics stimulate new creative opportunities and relationships within the practices of an inclusive music ensemble?***

This question was informed by on-going research into the digital score and the transformation of the music score through digital technologies with a focus on its impact on musicianship and creativity. For the purposes of this paper a digital score is defined as a 'communications interface of musical ideas between musicians utilizing the creative potential of digital technology' [65]. An important focus for this collaboration was how a digital score employing technology can be used as an inclusive vehicle for music-making especially for musicians who face barriers to music making. Therefore, this is not about design for disability, but rather an investigation into the potential of AI and robotics in promoting creative involvement for all musicians involved regardless of (dis)ability.

We collaborated with a physically disabled musician (Jess) and two non-disabled musicians (Clare and Deirdre) over an extended and iterative processes of workshopping and system development. We adopted a human-centered approach of supporting the musicians to explore how the system integrated and transformed their music making practice.

Our findings reveal that the musicians formed unexpected and distinct relationships with *Jess+* and viewed its role in the ensemble differently, but these were nonetheless inclusive and binding. Each musician perceived they were in-the-loop with the system, as they found it to be a good listener with its own creative 'voice'. It was non-judgmental and accepting, which, for our musicians, promoted a new freedom of expression and confidence in taking musical risks when improvising. Jess, as hoped, viewed the system as an additional layer of creativity and felt empowered by its inclusive potential. For Clare and Deirdre, they elevated the system beyond a tool that stimulates musical ideas to one of it being a 'creative accompanist'. Our findings shed new light on matters of human-AI co-creation and collaboration in artistic settings, the potential of such tools in flattening hierarchy's and promoting inclusivity, and some supporting design recommendations for their implementation in HCI research.

First, we highlight related work pertinent to our project, followed by a technical description of the creative-AI robot arm (*Jess+*) and the project set-up, methodology and approach. Following this we chart our findings which we then discuss to distil key observations.

2 RELATED WORK

In this section we discuss related work to the research context of this project. Although initiated by a conversation about knowledge exchange, the research imperative was very much informed by, and extends related work.

2.1 Meaning Making in Music Ensembles

A significant –if not the primary– element in the evaluation of this project was how it generated meaning amongst the musicians while music-making. For the purposes of this research project we understood musical creativity and meaning-making from the perspective of those doing the music. This adopts Christopher Small's notion of musicking [60] which he defines as "to music is to take part." Small wrote that "taking part can happen in any capacity," such as performing, composing, and listening (and dancing). It crucially states that meaning is formed in the relationships that are established within the realm of musicking, which, in a digital score context, can mean forming connections and relationships with agents, sounds, spaces, and presences that are encountered in here.

Music-making is an inherently social task. Most music is performed in groups, and are subjected to the influence of an audience, even if playing solo. Laura Bishop discusses this from a perceptual perspective. In her paper, she writes:

> "Music perception is social too: audiences recognize social relationships and communicative behavior between members of a performing ensemble [2, 46], and they infer human agency when hearing music–even without visual confirmation of a performer [36, 49], making sounded performances a means of interpersonal communication" [7].

Music-making is also creative, and in many music cultures music is generated via improvisation. For example, the jam session in the writing of a pop song, jazz solo's, folk music performances, or classical music extemporization on a piano before expanding to an orchestral score. Creativity occurs when play turns into invention; it describes the parts of human cognition that support the generation of such playful invention (an object, an idea, a musical improvisation) that is novel and significant to the perceiver [17].

In a research context, Bishop writes, creative output is "typically evaluated on the basis of its originality and appropriateness" [7]. She continues:

> "In artistic domains such as music performance, negotiating a balance between originality and appropriateness means maintaining flexibility within a given set of stylistic constraints. It is important not to confuse creativity with either originality, defined as the degree of novelty of a creative output relative to a given sample of related outputs, or value, the quality assigned to a creative output by a receiving audience [69]. Creativity is a component of cognition, while originality and value are evaluations made by others in the context of their own cultural experiences" [7].

2.2 Human-Machine Collaboration

We live in an age of increasing intersection and integration between humans and autonomous machines, a view also reflected through the HCI's community far reaching focus on such matters. One prominent topic in this field concerns human-machine collaboration, which foregrounds a broad range of concerns such as the negotiation of roles, autonomy and control [1, 5, 32], co-creativity [15, 37, 66], sense making [34, 52], and transparency, accountability and trust [4, 59] amongst others. Humans' relationships with autonomous technologies are nuanced and emerging, where the 'I' in HCI is increasingly reconsidered and reevaluated. For example, Mueller et al. [47] foreground Human-Computer Integration distinct from matters of interaction, with a focus on tight integration between technologies situated on, or in the human-body. They note, "one's self-image can be modified through technology by either changing the perception of ourselves or by physically changing ourselves." Whereas in the experimental AI artwork Message Ritual, Rajcic and McCormick [53] highlight a shift to 'human and non-human entanglements' and encourage us to imagine the types of relationships we may want with AI technology in the future, as opposed to engineered problem solving. We are

interested in exploring the entanglements of how our musicians relate, interact and integrate this AI robot arm in their ensemble playing.

2.3 Music with Robotics

This research project extends and enhances existing research in music co-creativity with robotics. For example, research in computational creativity [42], AI and music [45], and robotic musicianship [9, 35, 68]. This is a rich and emerging area with many solutions which are currently being developed, many of which are tackling in-the-loop solutions for human–robot music interaction. For example, the cooperative AI at the heart of "In A Silent Way" [43] is trained using performance data and communicates with the human musicians through real-time sound generation and emoticons to generate a sense of trust. Additionally, in *Design Considerations for Real-Time Collaboration with Creative Artificial Intelligence*, McCormack [44] offers a framework for maximizing the human–AI creative interaction, which can be migrated to human–robotic musicking. This has focused on enhancing creativity approaches to music and music-making. *Jess+* extends this by focusing on the embodied relationship among agent- robot, sound presence, human musician, and the flow of co-creativity, with the aim of transforming the creativity of humans.

2.4 Embodied AI and Human-Computer Integration

Understanding the nature of embodied AI, gets us to the heart of the design innovations that are introduced here in this paper. Embodied AI can mean robotics (i.e., the AI controlling the robot is reaching out into the world through a body). But within the realm of musicking, a body is only part of the communications and relations-building system, the bulk of this system is communicated through sound and a human's embodiment of their instrument. On this matter, Vear [66] wrote:

> "Embodiment (in music) is the process in musicking of drawing the musician's sound into their bodily sense of being. This presumes that when musicians make music, it is not a process of outputting sound into the world but an embodied experience of becoming the sound they create in the flow of musicking. Equally, it describes the process of the musician reaching out from this sense of becoming and drawing in the sounds of others so they feel their presence as sound. This is a dance of sorts: to touch, to feel, to sense, to work with, to play with, and to hide and seek and flirt and subvert with others through the flow."

To introduce an AI and a robot into this 'dance' it too needs to be designed and developed from an embodied perspective. As such, a definition of embodied AI adopted by this project is an "intelligent agent whose operational behaviour is determined by percepts interacting to the dynamic situation within which it operates" [48]. This definition is built on two principles: a) that artificial intelligence is not limited to the thinking-mind model, and b) that we understand meaning-making from the perspective of embodied cognition. This builds on Rodney Brooks's foundational work with behavioral AI (e.g., [10]) and his coping machines, however, the dynamic environment that these 'creatures' are to exist within (and "do something in this world") is music.

2.5 Inclusive Design for Music

There is a large body of work that looks at disability and music making from a range of perspectives. Our work is interested in the investigation of tools and technologies from the perspective of the social model of disability, i.e., for people with 'diverse abilities' [21]. Inclusive design for accessible digital music instruments (ADMI) typically should

include some form of participatory design (PD) from its user(s) (e.g., [21, 38, 67]). Participatory design for ADMI's is an important–and still emerging–topic for the HCI and NIME communities. In recent years PD has been challenged to also consider dialogic design [70] to ensure direct connection between user input and design decisions. Examples are numerous engaging with a range of technologies, settings and diverse abilities, such as for music therapy [12, 31] or education [20] or multi-sensory sonic spaces [26]. Other work focuses on reimagining existing instruments, for example guitars for neurodiversity [28] or physical disability [27], some of which are focused on bespoke designs for specific individuals [38] and hearing impairment [51]. Another area concerns adapting the control of existing user interfaces [18, 39] which extends to harnessing alternative gestural modes such as eye tracking [30], hand gestures [61], and finally brain controlled devices that explore affective state recognition driving generative music [14, 40].

In many of the above-mentioned cases, the ADMI's were designed with a musician-instrument relationship in mind, placing disabled musicians needs at the forefront (PD). While the base technology for *Jess+* already existed as a proof-of-concept, and barely viable prototype, we were interested in how to adapt and refine its gestural behaviours and interactions in response to the experience and needs of our inclusive ensemble.

2.6 Theoretical Context - The digital Score

A driving force underlying this *Jess+* research project is the work from an ongoing investigation into the digital score. This investigation is looking into the technological transformation of the music score and crucially to this paper, its impact upon creativity and musicianship. The digital score project proffers a theoretical framework with which to understand such technological transformation of creativity and musicianship. This framework takes a phenomenological approach and adopts elements of affordance, affect and embodied music cognition as well as extra-disciplinary theories such as from media studies and computer games. The focus of the framework is from the perspective of the flow of musicking (introduced in section 2.1). It defines flow as "the experience of musicking from the perspective of being inside the activity" and the "state in which people are so involved that nothing else seems to matter" [65]. Like Small's definition of musicking [60], the framework focuses attention on connections and relationships that are formed between the musicians and their digital scores, and offers a simple two-way structure of reading such relationships and connections from the perspectives of: *Taking in* - "within the flow, musicians make connections with the digital score as they reach out, suggest, offer and shift through the tendrils of affordance" [65]; *Taken into* – "the digital score can establish a world of creative possibilities for exploration through the flow" (idem).

3 DESIGN OF JESS+

3.1 Design Rationale

Jess+ was designed as an intelligent digital score system for shared creativity with a mixed ensemble of disabled and non-disabled musicians. It used an existing proof-of-concept AI-robot arm score-drawing experiment as the base technology. Working with this proof-of-concept served six purposes:

(1) The partners felt that it was an appropriate starting point as it offered a novel approach to expanding the orchestra and connected to many existing practices and protocols.
(2) It saved a lot of development time thereby speeding up the creative process.
(3) The musicians expressed excitement about working on the project and became invested in it from the start because they already were able to envisage its potential by seeing the original proof-of-concept.
(4) The arm could be used to draw scores on paper, or move in space as a conductor.

(5) It brought the AI out of the black-box and into the physical world.
(6) It moved in ways that might be perceived to be embodied in the music (like a the bio-signals of a conductor, or a lead violinist, or a dancer [16]).

3.2 System Design

The system design for *Jess+* uses a closed-loop interaction design as illustrated in (Figure 1). As a general overview the AI-stack (architecture) was a simple modular design of:

- *Layer 1* - percept input and formatting. This module manages and formats all the real time input data and sends it to the AI factory and gesture manager for processing.
- *Layer 2* - AI Factory. This module generates streams of data from the 7 neural network models that are housed in the AI factory. It's purpose is to generate a constant flow of predicted data from each model (emulating a busy mind negotiating options inside music-making).
- *Layer 3* - gesture manager. This module chooses one of the outputs from the AI factory (layer 2), or live input stream (layer 1) and holds this stream for a few sections before randomly choosing the next (we called these 'trains of thought'). There is a 'startled' function that interrupts these trains, when the live sound reaches a certain threshold.
- *Layer 4 - belief system* - robot choices and language. This module takes the single output stream from the gesture manager (layer 3), and uses its value to determine which of the pre-defined movement gestures the arm is to conduct, and also decides operational factors like speed, acceleration etc.

3.3 System Interaction

Diving deeper into the interaction design, as illustrated by the system flow in Figure 1, the system operates as:

- (Sound | Sensor data) this consists of two layers of input interaction (1) the sound from all the musicians, and (2) physiological data from the disabled musician (Jess).
- This data is processed and interpreted by an AI Factory [AI] module, consisting of 7 neural networks trained on movement, brainwave (electroencephalography (EEG)), skin conductance (electrodermal activity (EDA)), and musical data extracted from an Embodied Musicking Dataset of jazz pianists improvising. The real-time data is passed to the AI Factory (at about 10 Hz) for each neural net to make predictions of an abstract 'response intensity'.
- This stream of predicted response intensities is then passed to the [Thought train] module, which randomly chooses a stream and holds that for between 3-8 seconds (roughly the length of a Western music gesture/melodic line).
- From this chosen 'thought train' value, a robot gesture is determined from a fixed repository of predefined movements. Immediate parameters such as speed, scale, end point and velocity are determined using random processes, and the gesture is passed onto the [Robot arm], which moves in time and space.
- This [Gesture] is then interpreted by all the musicians who play improvised music, and Jess reacts physiologically to it, closing the loop. The main loop can also be bypassed when sound is too loud, interrupting the robot gestures with a 'startled' response and moving on to a new main cycle.

The role of the arm is to make embodied movements and present drawn gestures via attached pens onto a sheet of paper to inspire the musicians to make a sound and to co-create music through improvisation. The role of the AI is

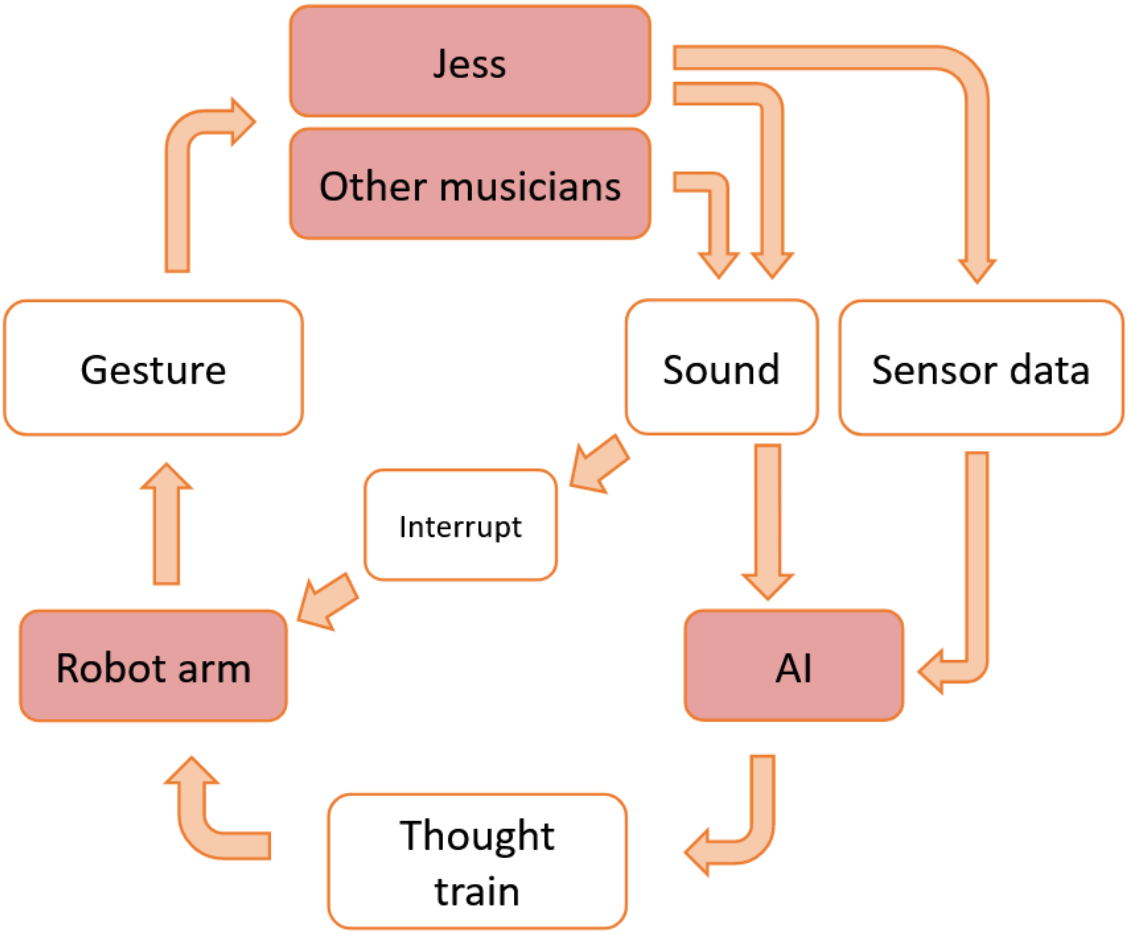


Fig. 1. Interaction Design of the Jess+ digital score

to sense the humans and to generate a response via the robot arm so that it is perceived as being meaningful in the flow of music-making. The sensing involves a single microphone that is listening to the collective sound produced by the human members of the ensemble, and brainwave EEG as well as skin arousal EDA input from Jess. The system contains a *belief system* that was built with the musicians and contained its aesthetic approach to robotic arm response. These predefined gestures were derived from two main sources of graphics scores, namely Cornelius Cardew's *Treatise* (discussed in [19]), and Christian Wolff's *For 1, 2, 3 Players* (discussed in [62]). Graphic scores are a type of music notation based on illustrations of visual shapes and markings, which are interpreted by musicians into sonic material.

It should be stressed that the movement of the robot arm was by no means functional; a by-product of moving a pen from one point on the paper to another so it could draw. In fact, quite the opposite: because the movement was controlled by the 'thought trains' that were produced by the AI Factory, which was trained on embodied data from jazz improvisers, the movement of the arm should be considered to be the notation (however abstract) with this inked

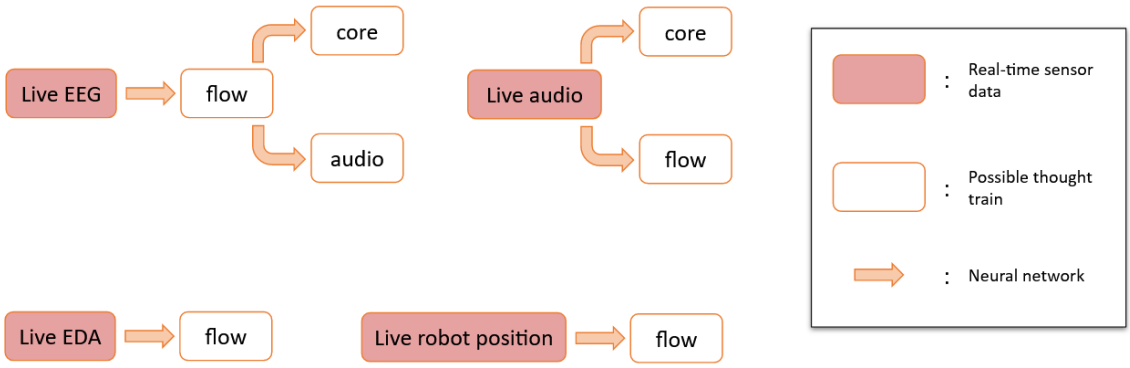


Fig. 2. Organisation of the Jess+ AI Factory

marks on the paper a by-product of this. This factor was embedded into each aspect of the AI design, and is reflected in the musicians viewing of the arm as a conductor, or section leader or dancer.

3.4 Technical Details (Basic)

3.4.1 AI Factory. Central to the design of this AI is the AI Factory. This consisted of 7 neural network models, trained on the Embodied Musicking Dataset to represent features from each other as:

- audio envelope predicting 'flow' (as evaluated by the musician)
- audio envelope predicting *core* position (position of the middle point between the musician's shoulders)
- *core* position predicting 'flow'
- EEG data predicting 'flow'
- EDA data predicting 'flow'
- 'flow' predicting *core* position
- 'flow' predicting audio envelope

All those models consisted of a convolutional encoder-decoder hourglass architecture, composed of 5 layers of neurons. The dataset was split into training and validation sets (75:25) and normalised to perform model training, using training and validation graphs to ensure no under- or over-fitting.

In real-time deployment, the different models used the features they have been trained on linked to live sensor data (EEG and EDA sensors worn by Jess, audio from the room's microphone) with the exception of the *core* position input – originally the position of the point between the musician's shoulders as measured with a camera – which was replaced by the robot arm's position to introduce a sense of self-awareness from the system.

Live sensor data was passed to one or a succession of the described neural networks to produce outputs (possible thought trains) for deciding robot movements, as described in Figure 2. These were predefined in advance and in consultation with the musicians. However, the system was allowed to make critical decisions with some randomness about speed, tempo, velocity, duration and interruption of each of these movements so as to surprise the human musicians.

3.4.2 Language. A gestural language was implemented in *Layer 4* of the system. This was a repository of fixed movement types that outlined the aesthetic nature of *Jess+* as a digital score (as opposed to an open drawing machine) and also enabled the musicians to contribute to this aesthetic by suggesting movements and inspiration points into this repository. Immediate parameters such as point location, speed, acceleration and size, for example, were chosen at random when the AI had made a decision about which movement gesture to use at a given moment.

We chose to see this language as a *belief system*, and as a way of embedding a focused understanding of what music is, rather than knowing everything about music and every gesture. This *belief system* attuned the AI's responses to a specific aesthetic, and aligned to the core definition of a digital score (see 2.6), as a communications package of a musical idea. Other interactive response parameters such as behaviours, weightings, speed range, and timings were considered to be part of this *belief system*. This allies with Barr et al.'s definition that of robotic belief as "an acceptance that something is true, or that it has trust or confidence in something" [3].

This language used in this digital score is a set of predefined symbolic gestures inspired by:

- basic shapes such as squares, triangles, starbursts, circles and starbursts
- drawing/movement gestures inspired by Cardew's composition *Teatise* (1967) [2]
- drawing/movement gestures inspired by Wolff's composition *For 1, 2, or 3 people* (1964) [3]
- off-page 3-dimensional gestures across the fenced space of the robot arm's movement

3.5 Approach

3.5.1 Method. We employed a practice-based approach [11, 22] for this investigation. The reason for this was to privilege the performers' insights on their practice while interacting with and through the *Jess+* system. These insights became the primary data for our investigation. The knowledge from practice-based research was generated by the core involvement of the three performers, their reflections on their involvement as demonstrated in findings section and the artefacts of their musicking interactions as captured in the video recordings [11]. To aid this, the musicians were briefed about the types of insights we sought through their involvement and practice. This brought the theoretical frameworks into the heart of the experience and strengthened the following discussions [11]. The case study was unique and specialized to the group of musicians involved and over a prolonged period of time and depth of engagement, therefore suited to capturing nuanced and context-specific factors [13]. Capturing the subjective experiences of the musicians involved qualitative methods which allowed for more in-depth explorations and analysis than would have been possible with a larger number of participants [50]. Additionally, as it was an exploratory study it involved the evaluation and assessment of research methods, design refinement and identifying potential variables for possible larger-scale future studies [13].

We conducted this enquiry in a 'safe space', a messy and flexible research lab where the musicians –supported by the research and development team– could explore, reflect, and discuss unshackled from outside influences and pressures. We focused on improvisation as the vehicle of music making – something that has happened frequently in inclusive design research (see [55]), because improvisation presented in this way is a "co-created activity that endeavours continuously to question exclusionary identities and assumptions." Furthermore, avoiding the performance of known or rehearsed material removes the composer-performer hierarchy, where performers perceive their role as one of reproducing a composers' instructions. Because of our approach we were offered a raw and exposed view on the ensemble's creative process with our creative-AI robot (*Jess+*).

[2] https://medium.com/nightingale/treatise-a-visual-symphony-of-information-design-2ced33ef01a0
[3] https://spiralcage.wordpress.com/2011/03/06/music-for-merce-part-2/christian-wolff-for-12-or-3-people

3.5.2 Process. We undertook an iterative process of system exploration and development through practice. The central activities in this process were 5 x 6hr workshops distributed over a 4-month duration. The structure of each workshop was open, but primarily consisted of cycles of improvisation with the *Jess+* system followed by reflective discussion. Iterations of system development were then conducted between workshops in response to feedback from the musicians (participatory design) or to address technical issues as they arose. The final workshop included a summary 'sharing' with the project partners, where the musicians played with *Jess+* and led discussions about their experience of it. We also conducted semi-structured interviews with the musicians at different stages of the process to capture their reflections. A summary description of how the process and system development unfolded is as follows:

(1) *First Workshop*: All stakeholders getting to know each other and the musicians first experience of improvising with *Jess+*. This initial prototype used consisted of audio input from the microphone and streams of random numbers processed to a primitive version of the AI Factory. Streams were selected randomly with equal probability and the response depended on the stream intensity. The Dobot Magician Lite robot[4] arm was drawing on a sheet of paper positioned on a low table, and only console logs were printed on a large screen in the room for monitoring by the research team.
(2) *Interview 1*: Individual semi-structured interviews were conducted online with the three musicians, capturing their musical background and experience with technology, perceptions on collaborative relationships in music making and reflections on first workshop.
(3) *Second Workshop* (57 days later to allow for the collaborative research design to be implemented): Musicians cycled through improvisations with *Jess+* using the Dobot robotic arm and subsequent discussions with the research team. For this workshop a more robust data management was implemented with the *Borg*[5]. Furthermore, additional robotic behaviours were implemented including off-page gestures. A testing mode was also implemented to enable the musicians to experiment each gesture individually.
(4) *Third Workshop* (16 days later): Continued improvisations and discussions as per previous workshop. The initial AI Factory was reworked for this workshop into a new one using encoder-decoder feature-to-feature models able to process live EEG and EDA streams from the sensors worn by the disabled musician, and a visualiser for those live physiological sensor data was implemented. The logic was modified to select audio 36% of the time as opposed to considering it at the same level as the other streams, and a silence listener was added so that the piece would finish if no sound was produced during a set time lapse. Finally we made the interruption from high stream values more responsive.
(5) *Fourth Workshop* (30 days later): A UFACTORY XArm robot arm[6] was introduced in this workshop. The musicians continued their process of improvising with the system and subsequent discussions. A number of configurations and appendages to the XArm were explored, such as 4 pens at the same time that can be individually chosen by the AI but also with a feather instead of a pen (experimenting a robotic dance instead of drawing), and off-page gestures were reworked. Stream selection information was added to the visualiser.
(6) *Interview 2*: Individual interviews were conducted online with the three musicians, reflecting back on the process as whole and their impressions of working with *Jess+*.

[4] https://www.dobot-robots.com/products/education/magician-lite.html
[5] https://www.oreilly.com/library/view/python-cookbook/0596001673/ch05s23.html, https://stackoverflow.com/questions/1318406/why-is-the-borg-pattern-better-than-the-singleton-pattern-in-python
[6] https://www.ufactory.cc/xarm-collaborative-robot/

(7) *Final Workshop* (19 days later): The final workshop was conducted in three stages: (1) musicians improvising with both the Dobot and XArm robot arms in the morning; (2) a sharing performance and discussion with the wider project partners in the afternoon; and finally (3) a summary group interview with the musicians. Final developments to *Jess+* employed here included a terminating sequence to indicate when the piece was ending, in addition to a starting sequence that was always present since the first versions of the system.

3.6 Data Capture and Analysis

Each workshop was video recorded using a webcam looking into the workshop room which captured a wide view of the musicians' improvisations and group discussions. Members of the research team and the PI also captured written notes. Within a workshop, these notes —which may have recorded observations of behaviours during an improvisation, or comments made in a discussion— were used to promote further discussion. Interviews conducted outside of the workshops were also captured on video (i.e., Microsoft Teams video calls) and subsequently transcribed. Between workshops, the project PI and researchers independently reviewed captured materials and made notes regarding comments and observations considered pertinent. These were then brought along to the next workshop to explore further. Consequently, the process shaped the topics the musicians and researchers considered interesting and important. After the final workshop a comprehensive review of notes —as developed over the course of the process— alongside the interview transcripts took place. Two data sessions were conducted, where the PI and researchers came together, compared notes and agreed on the findings to foreground.

3.7 Core Team

The core team consisted of the PI, two researchers, one software developer (the authors) and three musicians (who knew each other from previous music performance projects). At the start we asked the musicians to complete a basic 'musical' demographics survey:

3.7.1 Jess Fisher. Jess is a disabled musician and composer. Although restricted to an electric wheelchair due to cerebral palsy she regularly performs in inclusive ensembles and as a solo artist, using primary digital music tools and technologies (Figure 3). She worked with Digit Music[7] on the creation of a bespoke accessible music controller (CMPSR) which Jess typically interfaces with a range of contemporary digital audio workstation software. In ensemble settings Jess performs the music of other composers, typically using a bespoke music notation called 'arrow notation' which reflects the design of a CMPSR controller. Jess does on occasion improvise, but is not as familiar or comfortable in such musical settings.

3.7.2 Deirdre Bencsik and Clare Bhabra. Deirdre is a professional cellist and Clare a professional violinist who are both long-standing members of Sinfonia Viva, a UK based orchestra and educational organisation. Their performance practice is rooted in the classical tradition reading from standard western notation. Both Deirdre and Clare improvise in some community-based projects but both professed to not being confident improvisers. Neither employ any digital technology in their own practice, although Sinfonia Viva do sometimes collaborate with digital musicians and artists.

[7] https://digitmusic.co.uk/product/cmpsr/

Fig. 3. Jess performing with the Digit Music's *CMPSR* MIDI controller

4 FINDINGS

We present the findings as follows. The musicians' initial reflections at the first workshop improvising with *Jess+*, observations from subsequent workshops, which is followed by a detailing of the musicians' final reflections.

4.1 First Meeting

Over the course of the first workshop, the musicians undertook a journey through apprehension, a lack of understanding, surprise, and then to seeing potential.

Initially, Deirdre reflected she, "felt excited, open minded," but was nonetheless a little guarded, whereas Clare was concerned, "I didn't really know what to expect, or what use I could be to it, I'm not very technically minded."

It was clear from their initial improvisations with the base technology of *Jess+* they were keen to understand the logic of its actions. Clare noted, "The language that the robot's uses, or its actions I don't quite understand, maybe I'm not meant to understand them." Clare, was also "looking for patterns to provide some sense of security." Jess was uncertain about how she engages with it. On this she said:

> "We all had our guards up. We were sort of playing, but I wasn't playing to the best of my abilities because, if I play too loud (for example), will I destroy it? [...] I play with a lot of tech, but I tell Digit Music's *CMPSR* (Jess' music controller) what to do, *CMPSR* doesn't tell me what to do. This piece of tech was saying, 'you do your thing and I'm gonna do my thing', and that for me was very scary and made me feel a bit vulnerable."

They expressed surprise that *Jess+* responded to their musical gestures, "quite impressed because there was reaction to what we played, and I could see patterns occurring" (Deirdre), which was also echoed by Clare, "there was a pattern to how it listened and responded, a bit like a human, it reacted with a bit more feeling than a machine does." As they continued, an emerging awareness that a creative dialogue could take place, "I did feel it was making a contribution to the group, it wasn't trying to control the group [...] at the beginning I wanted it to control the group [...] It took me a while to realise we weren't playing a graphic score." Deirdre also discussed an initial expectation that the AI would be, or should be in control:

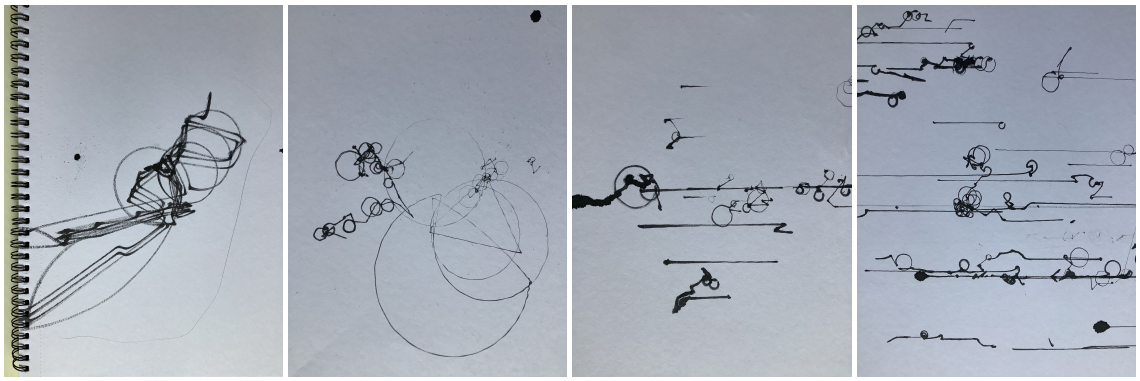
> "I didn't realise it would be able to do the listening that it could do [...] initially when I was playing with it, I wanted to do what it was telling me to do, so if it drew a circle I would play a circle, but it's not that at all, you literately need to play with it [...] Robot didn't only copy, robot almost digested what I gave it and came back with something else, which made me respond to the else."

Jess immediately saw the potential of using the EEG headset and EDA sensor in the system, which excited her:

> "Taking my brain waves and allowing me to see what my brain feels with music–not exactly, but it, you know–it made me connect with music on a whole other level. And actually, made me realize, 'Ohh music doesn't just have to be everyone pick up an instrument,' you know, if someone physically can't do that for whatever reason, this could be a whole other way that they can have an input to music by letting their brain waves take care of it."

By the end the musicians started to acknowledge that an understanding of the AI might not be necessary after all to engage and improvise with the system, "I don't need to know how my car gets me from A to B. But I do need to trust it and trust that it will get me from A to B without any harm" (Deirdre).

In summary, they collectively noted the 'feel' of *Jess+* seamed 'right', meaning the level of felt co-operation between the system and the musicians was appropriate, such as the gestures it drew, and velocity and intensity of movements aligned to their musical responses. The palette of drawn gestures, as inspired from prominent graphic score notations were familiar enough to the musicians to be meaningful and inspire musical action, "I could really see the layers of how it was programmed" (Clare): the little textual drawings inspired delicate musical actions in reply (see Figure 4a), and



(a) (b) (c) (d)

Fig. 4. Jess+ Drawings made by the Dobot robot arm

surprising contrasts, such as the big repetitive gestures (see Figure 4b) were effective at eliciting surprising musical gestures in return. On occasion they would revisit previously drawn gestures which inspired ideas of memory, from which they could revisit previous musical themes (see Figure 4c). Straight line markings (linear left to right) felt like a storyteller (see Figure 4d) and different areas of random clusters of markings inspired the musicians to change their thematic material. And finally, when the robot arm's gestures extended off the page, i.e., in 3D space, rather than making markings on the page, it was interpreted by Deirdre and Clare as a prompt to explore extended techniques on their respective stringed instruments (e.g., playing off the strings).

4.2 Getting to Know Each Other

Over the course of the following three workshops (n.2-4) the musicians continued to work with *Jess+*, with each workshop followed by some responding technology development work (see 3.5.2 for further details on system development). Here, we foreground specific observations, discussions and milestones.

4.2.1 Understanding Interaction. Throughout the workshops, the three musicians professed to observe developments in the AI system that took place between workshops, each time for the better, claiming the gestures the robot was making were increasingly 'expressive', "those gestures have become more balletic, more extreme more varied and actually more life-like" (Deirdre). These related to additional implementation of off-page gestures in 3D space (in response to the musicians feedback in workshop 1), refinements to the weightings of symbolic gestures called upon in the AI factory (see 3.4.2), and the introduction of the UFACTORY XArm robot arm with 6 degrees of freedom in workshop 4.

Throughout the workshops the musicians described feeling connected to *Jess+*, declaring that they could tell it was 'listening' to them. Some objective evidence for these claims came from workshops 2 and 4 when–after an instance of improvisation–the musicians voiced a dissatisfaction, or a sense of disconnection from the system. On each occasion we discovered the microphone was not working, meaning the AI's gestural choices were not being driven by human input. Clare noted, "I knew there was a problem. I didn't know what the problem was [...] I definitely could feel it when it was rectified. It was a huge jump. 'Okay, ah', that's what I couldn't tell you," and Deirdre observed, "It wasn't at all enjoyable [there was] no interaction between us."

4.2.2 'Baby Robot' Arm and 'Grown-Up Robot' Arm. We employed two different robot arms over the course of the 5 workshops, transitioning from a small Dobot desktop arm to a larger UFACTORY XArm in the fourth workshop (see Figure 5 and refer to section 3.5.2), with both being used in the sharing (workshop 5). The researchers anticipated a great deal of resistance to swapping the robots mid-way through the development process but were surprised that all the musicians greeted it as if it was the original, small Dobot, that had matured. One mentioned that it looks like it had gone through puberty and grown-up. This indicated that their bonding with the robot was not through the physicality of the mechanical instrument, but as a behavioral agent who played music with them.

With the small robot arm it exclusively moved and drew graphic markings on sheets of paper (see Figures 4 and 5a). But with the introduction of the larger XArm robot a new palette of expressive movement was now possible, and this changed the focus of the discussion and prompted a number of adaptations to the physical gesturing of arm. This included moving from a single marker pen to a cluster of four coloured pens attached to the arm's head, so that the changing angle of the head would result in different coloured markings on the paper (see Figure 5b). The mechanical gestures made by the larger robot arm (with more degrees of freedom compared to the Dobot arm) were considered to be more evocative and balletic. As a result there was a shift away from the arm drawing onto a 2D plane (i.e., on paper), so the pens were removed and, along with some y-axis reconfiguration, the arm then gestured in 3D space.

The team also explored further augmentations of the larger arm, which included trying out various appendages attached to the arm's head such as a glove ('just creepy'), thin strips of material hanging from the arm, which were considered to diminish the 3D gestures and finally a feathery cat toy, which they liked and kept for subsequent improvisations (Figure 5c).

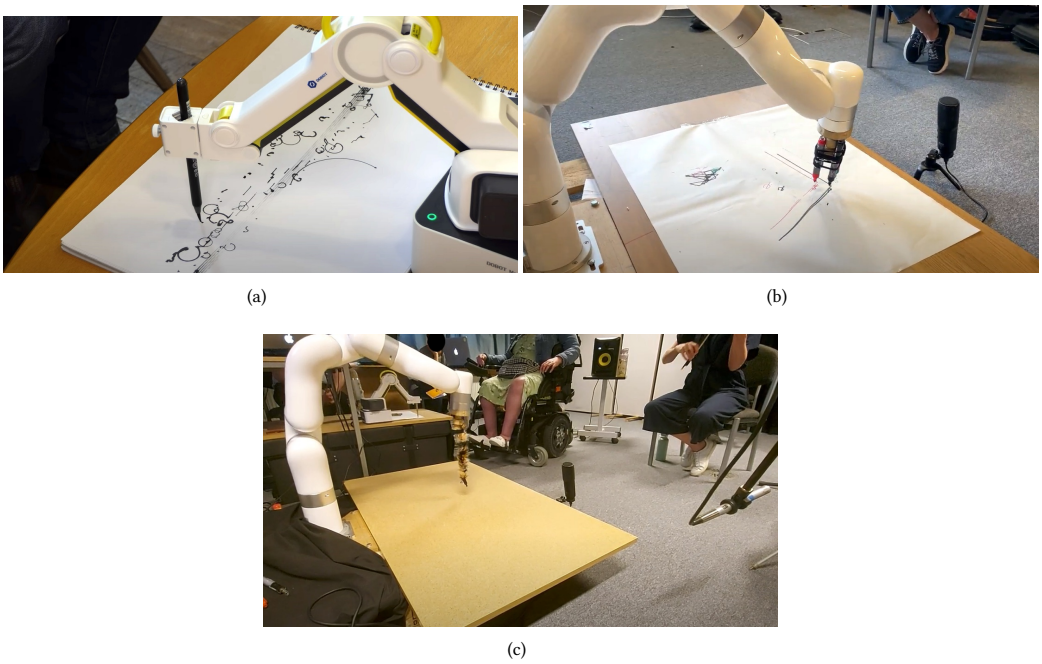
4.2.3 Rules. There was a discussion in the second workshop about whether to establish some underpinning rules or structures for the musicians to frame their improvisational practice with *Jess+*. This conversation was prompted partly to stimulate them to think about their emerging creative practice, but also to elucidate any further development needs. In reply, the musicians established a high-level rule of "you can play whenever and whatever you want." This appeared to be a significant moment, as up until this point they had been–mostly–led by the robot; when it started, they started, when it gestured, they gestured, and when it stopped they stopped. Setting this ground rule appeared to represent a step away from a perception that *Jess+* was in control and they all had shared responsibility for progressing the improvisation.

4.2.4 Introducing Jess+ to Colleagues. In the afternoon of the final workshop, we conducted a sharing session for our project partners (i.e., Orchestras Live and Sinfonia Viva), so they could see the culmination of the work to date and hear from the musicians. The musicians led this sharing, and in preparations for this beforehand they appeared concerned that their work would not be understood by those spectating. We observed them assume a responsibility for promoting the system, wanting it to be understood and appreciated in the same way they do. Deirdre, in particular, was keen to explain to the partners the value of their experience and to encourage them to try it for themselves. She stated:

> "[It was] absolutely vital to be able to explain what was going on and I'm not sure that we managed enough of that, which is why I suggested that they try it, because when you experience it and that gives you more of somebody else's flavour of it."

Below are three video links to performances from the sharing session with our project partners:

- https://youtu.be/MBPQNmAXvXk
- https://youtu.be/7dQKIpjKJu4



(a) (b)

(c)

Fig. 5. 3 generations of Jess+ Robot Arm system. (a) Dobot with ink pen on paper; (b) xARM with multi-coloured pens drawing paper; (c) xARM with a feather attached to its end

- https://youtu.be/sK4KAmv3ikw

4.3 Reflections

> "It tells a story of bringing three completely different people from different backgrounds into a warm safe space where you can put down the rule book and not necessarily think about it as a score you look at, and it enhances your ability to be creative and to actually get back to a comfortable state of improvising" (Jess).

In the following section we present the musicians summative reflections using their own words. They illustrate their experience of the project, the nature of their interactions with *Jess+*, how they see its role and relationship in the ensemble, and the subsequent effect of this on their music making with it.

4.3.1 General Thoughts on their Experience.

> "We're definitely living in an age were so many things are possible regarding music and what you could have alongside you to support you, and there's been this weird development in me [over the course of the project] where the arm itself could come in handy helping to write a score, or giving someone who isn't able to physically play an instrument use the headband (i.e., EEG), they could then have a role in that. It's just saying that there is more potential out there for the way that technology can embrace the way that music making is done" (Jess).

The above quote was Jess' response to the question, 'tell us your initial reflections on the project'. Clare's initial response to this question describes *Jess+* introducing something new, an additionality into their practice:

> "If I try and explain to other people what I'm doing [on this project] they all go, 'Oh, surely wouldn't want that. It's taking away,' but we don't feel that at all do we? It does not take the part of a human musician. It's something else, it's adding something."

Deirdre also riffs on the theme of additionality:

> "The influence of the robot has definitely made an impact on me as a musician, and I think it has added to the music that the three of us make. If I try and quantify what 'addedness' is, it has taken away decision making from each individual. That has sometimes given the robot the leading role, but it's not been stuck in that place, we can take the lead from it."

All the musicians perceived a development in the behaviours of the robot over the course of the project, as Deirdre highlights, "Those gestures have become more balletic, more extreme more varied and actually more life-like" and Clare adds, "whereas, at the beginning, it was still amazing, but it was a bit more restricted."

4.3.2 Interacting with Jess+. Thinking about perceived interaction with *Jess+*, Deirdre states "the most important point is it's listening." She goes on to discuss how their perception of this developed:

> "When we started the project, I think we mostly followed, because we wanted to discover what the arm would do and we were testing, 'was it really listening?' And actually, we knew when it wasn't listening when there was a problem with the microphone, we sensed that".

Jess extends this reflection, "I also like that it's has its own choice to listen to me or do what it wants [...] it's not copying what we're doing it's interpreting it, so for me the beauty is what does the arm interpret from what we play." Deirdre has similar thoughts, "It's not telling us what to do, it's not directing us like a conductor, it's part of the band like a musician, but it's helping us do what we do." Clare highlights the importance of this interaction, "Yes, sometimes it's leading. Yeah, sometimes it's following. And it's a vital part of the performance, it wouldn't be the same if it wasn't for the robot." Clare uses the analogy of talking to a friend to describe turn taking:

> "Sometimes you have to wait for them to talk and you have to wait for the right moment [to respond] and it's a bit like that. So, there isn't any right or wrong moment, but it may not be when you want it to be. Just like a person won't necessarily start to talk to you when you want them to."

However, if the system malfunctions this can have a profound impact on the musicians, as Clare describes, "It'd be helpful if we knew whether the robot was just thinking and just listening or whether it had just switched off". Clare goes on to describe the consequence of those moments:

> "[You] just feel a bit silly. When you're improvising, you are quite vulnerable. And that's why you need to be in a safe ensemble. And you know, if you trust the people that you're playing with, then it's fine to be vulnerable. And that brings out some really good music making. But then if you find that one of the players, and in this case it's the robot and it's just switched off. It makes you feel awful, doesn't it? I put my trust in you and it's not being reciprocated."

A recurring topic was the idea that *Jess+* was accepting and non-judgmental, "It's not a human and some of that is a good thing. You can't annoy it, or insult it, and we don't feel annoyed or insulted by it, as it's inanimate. For that

reason, it's a bonus and that feels good" (Deirdre). Jess illustrates on this point, "The arm doesn't care if I've performed the worst piece of music in my entire life, equally the arm doesn't care if I just performed like Mozart."

This in turn encouraged a musical freedom they would not normally experience, as Deirdre explains:

> "As the project has gone on, we've let the robot do what it wants to do and gone –what Jess would call 'freestyle'– without any worry about doing that, because we know we could come back. Sometimes I just thought 'right, I'm going to play something now and see if you follow me,' and leave the robot to do what's it's doing, and that feel is ok. Had it been a [human] musician, I'm not sure I would have done that, I think that would have been a little rude actually! As a result of that I might be more creative rather than responsive."

Deirdre details an example of this in action, "Once or twice I deliberately changed the pulse, I went from 4/4 time to 3/4 and that was direct challenge to see what would happen, and Jess and Clare came with me, and the robot came too. I'm not saying it changed time, because it's not in a time, but it didn't stay where it was, that's for sure." Expanding on this topic Clare and Deirdre agreed playing with this system could remove those tensions and uncomfortable social interactions other humans can introduce. "I can really see it working because it gets rid of expectations and judgements that have been a problem in the past" (Deirdre).

These comments, and others, illustrate an emerging freedom to take musical risks, an opportunity to experiment musically, to challenge themselves and the system. We observed Clare and Dierdre focusing intently on the robot arm throughout the improvisations:

> "Ideally, you always want your instrument to be an extension of you and this forces it to, because you shift your focus onto this [robot] [...] we're not thinking about performance or how you're going to do it again better, we're just in the moment" (Clare).

In contrast, and interestingly, Jess claimed she –mostly– did not focus on the robot arm when they improvised, rather she just listened and responded to Clare and Deirdre.

4.3.3 Roles. We invited the musicians to discuss how they perceived the role or purpose of *Jess+* in their ensemble, their views differed. For example, Jess observed:

> "I think the arm is an extra layer of creativity, I know in the past Clare and Deirdre have said they see it like another musician, I don't see it like that because it's not actually playing anything, so for me it's more that it's an extra layer."

To illustrate further Jess uses an analogy of technicians back-stage at a concert that control other performance media and support the on-stage musicians.

Clare struggled to find appropriate terminology, "a performer, a player. Okay, a colleague, maybe. Okay... um... leader." At other points in the project, she chose 'creative inspiration' and also 'creative accompanist.' Deirdre, similarly, hovered between terms, using, 'creative collaborator' and 'creative accompanist.'

Jess outlined how she saw the specific purpose of *Jess+* as a score creator, "It is here to help me, and I know its role is to write a score. I think the score is the end product, but the score can be the interpretation and almost the memory (of our improvisations)." Whereas Clare describes the relationships in this human-AI ensemble differently:

> "[*Jess+* was] one part in a group of four or five, if you include the headband. I'm sort of thinking of it as three human components, making a band, but each being influenced by this central performer, I suppose, in the robot. I feel as if we have a communication going between us [human performers] and

> there's a communication going to the robot as well. And whatever communication I'm having with the robot, I'm also influencing the band members." (Later Clare backtracked from the term 'central performer' reverting back to 'creative inspiration', or 'leader').

Deirdre's description of relationships was simple but illustrative, "a cake cut into four, a circle with four equal triangles [...] they all meet in the middle."

Both Clare and Deirdre enjoyed the robot in its drawing configuration, but nonetheless expressed a preference for the off-page gesturing (in 3D space) that came along later in the workshops "because in a way, if you're responding to the drawing, you're already one stage behind, aren't you?" (Clare) and "the development of the arm into fluent gestures made a huge difference to me in creating and improvising with it" (Deirdre). Jess was not happy about this change, "I struggled when the pens got removed. I kind of felt like we were telling it we didn't like its chosen career path (i.e., its original configuration to draw)." Obviously, this disrupted Jess' view of *Jess+* as a score creator.

Finally, Jess proposed some other contexts where she thought the system could offer benefit, specifically in educational settings for young people, and as a sensory tool in a performance (focusing on its balletic gestures). Finally, she also envisaged the usefulness of the system for herself, working alone in the studio as it would provide a connection to something instead of working in isolation.

4.3.4 Effect on Musicianship.

> "It drives you to want to play more [...] it almost gives you that inspired creativity, it helps to force the music out of you. I love it when Deirdre is trying to get a reaction out of it, it drives you to be a better musician, it drives you to think more about what you are playing" (Jess).

All the musicians described some enhancement of their musical practice. All felt they had become more confident improvisers, as Clare noted, "As a classical musician not being used to improvisation, it's breaking down the rules to help me improvise and to be freer," going on to reveal, "I gained a lot of confidence and could imagine embracing future improv[isation] sessions, especially in my outreach work, with a lot more experience." Reflecting on freedom, Clare considered whether the removal of constraints was a contributing factor:

> "I don't know whether that's just me getting to know the robot or letting myself get better. But certainly, by taking away parameters, and taking away the necessity of dots on a page and looking at movement [...] definitely freed me up an awful lot more and made me a freer improviser than I was."

Jess noted this experience of improvisation was different to her prior experiences, "With this particular project, we've not known what's coming, we're not prepared and that's brought down a lot of walls in ourselves as musicians. It's almost freeing in some ways and in some ways, it takes you back to why you fell in love with music in the first place." Jess reflects further, "I think it's changed my interpretation of what I think improvising is. It's really nice just to dig deep into that." More philosophically Jess reflects specifically on the use of tools such as biosensors (e.g., EEG and EDA) in challenging notions of musicianship, postulating, "do we need to start changing the way that music is conceived? So yes, you can hear physical musicians. But also, what is a musician? Do we need to maybe look at how we redefine what is a musician?"

5 DISCUSSION

It is clear from our findings that in this instance, and with this group, the musicians had a positive experience, one beyond their (and our) expectations. It stimulated new perspectives on the role of technologies within their social music

making and the inclusivity such technologies can promote among all musicians involved, and finally it transformed their improvisational practice. In the following we return to our research question and discuss the findings through this lens. We present insights that emerged through the analysis of the interviews and questionnaires, and an evaluation of discussions between the musicians and researchers. In doing so we draw out some design insights for human engagements with creative AI and robots in general.

5.1 Transforming Human-AI Relationships: Jess

How the musicians viewed *Jess+* and its role within their ensemble practice was a repeated topic of conversation. Initially, they viewed *Jess+* as a form of real-time, generating graphic score or a conductor and the musicians also found familiarity in these concepts as an initial point of engagement. However, as the process unfolded these roles were rejected and reformed.

5.1.1 Clear Ambiguity. The framing of the project (i.e., 'extend the creativity of a disabled musician') and its title–*Jess+*– established our initial view on the role of the system in the ensemble, namely an extension of Jess, and furthermore the primary relationship being between Jess and the AI. Jess was open to this position, although she chose to describe it as an additional layer of creativity and our findings certainly describe a transformation of her creativity. What was unexpected, however, was how Jes s–for the most part– viewed the purpose of *Jess+* as a drawing memory machine. For Jess, it was not a score for the moment of music making, but rather a visual representation of the AI's interpretation of their improvisation using the sound and her bio-data as its source material. This visual output could then be used after the fact to inspire future music making. This created an intriguing disarrangement as to who (or what) is taking inspiration from what (or whom) to perpetuate the invention in the improvisation. But interestingly this did not get in the way of creative invention within the musicians: they seemed to be content with this difference in perspective.

> ***Design Insight 1****: We were surprised by the difference in the relationships formed between human musicians and the creative-AI. Purposely working to abstract relationships in human-AI interactions may feel counter-intuitive, but it could lead to enhanced and positive interactions. This insight draws us to Gaver et al.'s account of ambiguity in design, specifically that "ambiguity of relationship creates the condition for a deeply personal projection of imagination and values onto a design" [23], but also Rajic and McCormick's observation of the importance to highlight the "the open nature of interpretation of machine generated" outputs [53].*

5.1.2 Robot as Extension. We noted Jess' response when Clare and Deirdre suggested that the pens be removed from the arm and just have the robot arm gesturing in 3D space. This raised a strong objection from Jess about the rights of the arm to be "complete" and to not "take away its right to be whole". Aside from the clear alignment to disability rights expressed by Jess, it was also accordant with her view of it as an extension/layer of herself, and is clearly a relationship that is deeper than the robot being merely a drawing machine.

This disarrangement in what the relationship is for Jess –drawing arm vs extension of herself– hints at, on the one hand that the technology plays a supportive role (see Lubart et al.'s [37] model of *humans supported by robots*), and on the other with her close attunement to it through her brain control. A key topic in brain control and physiological sensor interface research concerns the lack of control and awareness humans are able to exert through physiological interaction [52]. An experimental investigation of Jess' engagement with the EEG and EDA was out of scope for this project, but it is probably safe to assume Jess' physiological data, streamed while undertaking the task of improvising

with the other musicians, was most probably donated unconsciously (i.e., unaware of its effect on the system) and involuntarily (i.e., controlled by a computer but personalized) [52]. This raises the question as to whether this 'extension of herself' as driven by (largely) passive physiological data can constitute an extension of her creativity. The short answer from Jess was 'yes'. She was engaged in the activity of music making; she was listening to other musicians, sense making in the moment, leading and responding, essentially being creative, all of which shaped her cognitive and dermal physiology. She invited *Jess+* to creatively interpret her data, and perhaps it hints at it extending her sense of self.

> ***Design Insight 2****: We infer that the relationships between humans and creative-AI/robots are deeper than one is able to reflect upon. What a user/subject says, might be different to what is really going on. We strongly encourage you to ask around this phenomenon as direct questioning may not lead to direct insights. This could be particularly pertinent to the practice-based research tool kit, or settings that involve a practitioner's deep and extended engagement with such technologies. As such it goes hand in hand with matters of human-machine relationships, as highlighted in our first design insight.*

5.1.3 Redefining What a Musician Is. Jess was very excited at the potential of the biosensor systems to equalize 'ability', so as to promote inclusivity in creative practice. For her, the bio-sensor loop in our system design expressed no bias, awareness or interest in the sensor wearers' physical capabilities. We were intrigued by Jess' comment in relation to matters of inclusion and future applications of technology (such as EEG and EDA), "Do we need to maybe look at how we redefine what is a musician?" Jess appeared to be challenging the notion that a musician is always someone who actuates a physical instrument and is in direct control of sonic production, rather Jess speculates a future of symbiotic human-AI musicians, where the human might be potentially several (creative) steps away from instigating sonic production.

> ***Design Insight 3****: We observed the application of biosensors as an inclusive mode for interaction design (in the setting of physical disabilities). Harness their openness for interpretation as a design strength, which makes them particularly suited to interfacing with black box AIs. The deployment bio-sensing technology to facilitate inclusive and exploratory creative practice in educational settings–a setting proposed by Jess–is a good example, given the flexibility of such technologies to interface with a range of media systems whilst drawing participants into human-tech relationships. Future work should focus on perceptions of inclusively and control.*

5.2 Transforming Human-AI Relationships: Clare and Deirdre

5.2.1 Non-judgemental Creative Accompanist. Clare and Deirdre defined a different role for *Jess+*: they described it as a creative accompanist/inspiration. This was an interesting definition for a number of reasons. *Jess+* was not a sonic collaborator, but rather it offered stimulating visual gestures (what Kantosalo and Toivonen refer to as divided co-creativity [33]), whereas the term 'accompanist' implies a musical contribution (they also toyed with the term 'musician'). Furthermore, it implies a role free from hierarchy, i.e., it is not a subordinate or assistive role, nor is it a conductor, all of which implies a hierarchy of control. Their definition also illustrates that they perceived being in-the-loop with the system, recognising back and forth interaction. They found the system to be a stimulating, sensitive and empathetic accompanist, which expressed a number of human and non-human qualities they found advantageous: it listened, it was expressive, it contributed to the creative output of the ensemble, it was reliable (when the humans did

not make mistakes in configuring the microphone). Furthermore, it was perceived to be accepting and non-judgmental, it did not have an ego or an agenda; qualities that describe a persona.

> ***Design Insight 4****: Jess+ was designed to operate with human musicians inside their music-making. This was purposefully created to stimulate creative relationships. This is opposed to building creative-AI that is designed to simulate the role of a human in a creative relationship.*

5.2.2 Task Distribution. When viewing AI as a co-creator, Benford et al. [4] suggests definition of a persona for the AI might help "influence the human's creative experience." Shneiderman [58] however, offers words of caution, encouraging AI designers to pull back from emulating human characteristics as a universal goal, but rather exploit only those specifically required for the task and let the rest of it just be a machine. In our case some of the machine's –arguably non-human– characteristics (e.g., non-judgmental and inclusive) proved particularly effective.

Stepping back to the role of *Jess+* in the ensemble, task distribution [54] seems an important factor. Although Clare and Deirdre described the system as an equal partner, attended to it throughout, and described the positive impact on their musical practice (which we discuss later), they nonetheless had power of interpretation and also veto over this silent partner: simply *Jess+* can be ignored, as *Jess+* can ignore them. In future work it would be interesting to compare our experience here with one where the robot contributed directly to the musical gestures of the ensemble.

> ***Design Insight 5****: Our creative-Al robot is assigned a task distinct from the human task responsible for generating the principal creative output/product. This configuration can in turn promote human collaborators to engage deeply and form a rich creative dialogue with the outputs of the system, secure that they can exert control if and/or when required. Consider interaction design metaphors that remove undesirable human qualities in collaborative settings. This design insight is particularly relevant to integration of AIs in creative settings and practices, where interpretation, call and response and improvisation might be characteristics. This promotes the application of AIs not for the generation of final creative outputs (i.e., music, images, video, text), but rather to offer stimulation, guidance, sensitizing materials and fresh perspectives on the humans' activities.*

5.3 Enhancing Music Making and Practices

We have discussed at length the roles and relationships our three musicians formed to *Jess+*, in the following we consider the impact of these on their music making.

5.3.1 Independent Systems. The benefits of interacting with the system had transformative effects on the musicianship of the inclusive ensemble. Shared effort investment into the system –from the musicians– returned a deep sense of flow [66], as discussed above. The system demonstrated an independence within the shared goal of music making [41], and it appeared to be enough for the musicians to know that the system would listen and do something, sometimes but not all the time. The non-disabled musicians felt that they could take risks musically and challenge the system as a collaborative partner, which in turn unshackled their improvisational approach. While this is an exploratory process of finding common ground, it also speaks to matters of human-machine control. Hazzard et al. [29] view control in human-machine interaction from the perspective of aesthetic failure. Their taxonomy presents dimensions of control (i.e., the degree which a performer is submissive or assertive to the system) and failure (i.e., their desire to shun or embrace it). In our setting, failure can be replaced by risk taking, as we observed Clare and Deirdre early in the process *game the system* [29] trying to assert control over the system by deliberately provoking and learning its responses,

which later became *riding the system*, i.e., giving themselves up to both risk taking and direction from the system, "under this approach the system may take the performer to unusual places that demand creative responses" [29].

We note our musicians eschewed setting performance rules and the removal of materials that felt like scores (i.e., instructions) and as the workshops unfolded, they increasingly enjoyed the freedom of expression (taking risks) and the music they were making in an open configuration with *Jess+*, which resulted in Clare and Deirdre's final reflection that it had helped them develop into more confident improvisers. Greenhalgh et al. [25] proposes the concept of 'looseness' as a design consideration for human-autonomous machine interaction (in their case a music recognition system), where a tightly constrained system in turn constrains a performer's ability to be expressive, whereas a 'loose' system in turn offers flexibility through which a performer can extemporize and still provide what the system requires. The degree of 'looseness' is negotiated through both the human and machine [25] via a process of attunement over time [63]. While our system is not concerned with accurate music recognition, the concept still resonates: our musicians initially wanted a degree of tightness, i.e., to form and desire tight mappings between human-system or system-human, but their position softened over time, and they increasingly embraced a loose approach to their collaboration, resulting in an enriched improvisational practice.

> ***Design Insight 6****: If artistic freedom and flexibility is required from humans in a human-AI system, design out constraints of interaction where possible, so as to enable performers to take risks and engage freely with system outputs. This, of course, relies on building a sense of trustworthiness with such systems. A particular focus, therefore, of designing out such constraints is to design in trust and trustworthiness through careful engagement strategies.*

5.3.2 Emotional Expression. For Jess, the system allowed her to express the emotions she is sometimes not able to express through her current digital tools. Being extended through the system meant that she could express her feelings permanently into a score (when the robot was drawing). "I wanted to explore that part of me and I wanted, you know, I want my emotions that are in here to get expressed outwardly through that" (Jess). Thus, the extension of Jess's musical creativity as a composer and a member of the ensemble is directly enabled by the system. When one considers that Jess is feeling different emotions as she is engaged in musicking with the other musicians, her brain and body are also engaged and reflect this. One can feel different emotions in the different contexts of musical experience which engage the body in different ways. To this end, it is useful to consider the mind as embodied and in Jess' case also extended through the biological sensors [64].

5.3.3 Group Dynamics and Skills. We observe that the type of creativity that the musicians entered with the *Jess+* system has arisen from the group dynamics sometimes referred to as emergent novelty by Sawyer [56]. Bown also emphasizes that collective dynamics are inherent in artistic behaviour where ideas arise, "not because individuals think of them, but through a jumble of social interaction" [8]. This view of creativity involves the possibility of involvement with nonhuman actors and is a phenomenon that arises in relationships between people and their surroundings.

Here, we also think that musicians' creativity in the ensemble was helped by the social dimension and their previous playing relationships [57]. This allowed for the possibility of constant adjustments and exchanges over the controls of musical interactions in the improvisation between human and non-human actors, and the ability to take a step into the unknown when forming a new relationship with the system. These types of interactions provided a safe space for experimentation, learning and skill improvement. As a result of interacting with the system, Clare and Deirdre stated that their improvisational skills improved. They felt like they gained a lot of confidence that could help in future

improvisation sessions, especially in their school outreach projects. They also thought that improvising with *Jess+* could be a transferable skill to any other project requiring improvisation. *Jess+* offered a novel experience of performance for them as traditionally they are used to performing pre-composed and pre-rehearsed music instead of creating in the moment of performance.

5.3.4 Power (re)Balance. Jess felt that this project extends the meaning of what a musician is or how it is traditionally defined in music. Previously, she had to redefine that through her journey as a disabled musician but *Jess+* still offers something new because it changes the way music is conceived for both disabled and non-disabled musicians. She hopes that playing with the system could help break down stereotypes of what the term musician could mean in the future. She and other musicians also expressed that playing with the system gets rid of the expectations and judgments that playing with other human musicians could imply, getting rid of unnecessary negatives in human interactions that are not about music-making.

5.4 Knowledge Exchange

Finally, we return to our project partners, Orchestras Live and Sinfonia Viva who instigated this project, as outlined in the introduction. On the whole both felt that *Jess+* had "exciting potential for opening up new ways of working," for orchestras and for outreach community engagement. They suggested the system as-is "could be a real asset for creative teams from orchestras and other arts organisations in adding another dimension to workshop delivery." Furthermore, opening up the vocabulary of the robot's gestures away from a focused score approach, could "open up the field for those unable to physically pick up an instrument through the other sensory technology." However, they advised that a "lot of thought should be given to appropriate ways of explaining and introducing the AI to diverse groups of people, including those with additional needs, to ensure people feel comfortable about this unusual form of improvisation, composition and performance."

Both partners were taken by the experience of Jess, and especially how she didn't feel judged. They both felt that this was a positive outcome of the proof-of-concept, and could be a great beneficial factor when working with people who face physical barriers to making and playing music. However, they had concerns about the amount of technical support that would be required to deliver the project in its current proof-of-concept form.

They were excited by our approach to remove "physical and educational barriers such as sheet music or any kind of notion of 'music' [notation] but simply playing with sound worlds." Nonetheless, they did highlight the proficiency of the musicians we engaged with and whether it would similarly create a "safe environment for fledgling players with profound physical barriers to making music."

Finally, they saw potential in the arm operating on a sliding scale of responses from literal sound -> movement gestures through to co-creation as witnessed in *Jess+*. They felt that this would "be more of an exploratory interactive musical conversation, helping to develop the participants' creative imagination and initiative. This might be especially useful for people who initially struggle with the total freedom of interaction and who could prefer a more structured starting point." Additionally, this approach could give a "greater scope for inclusion of special education needs and disabilities people who prefer dance and who could develop 'in the moment' choreography with the arm being a member of the ensemble."

These high-level reflections offer a useful steer on the direction of future work and identification of some key challenges for us to address along the way.

6 CONCLUSIONS

In the *Jess+* project we partnered with two organisations interested in exploring the potential of digital scores built using AI/robotics. The focus of the exploration was to seek to understand how a digital score created using AI and robotics could stimulate new creative opportunities and relationships within the practices of an inclusive music ensemble. To do this we collaborated with a disabled musician and two non-disabled musicians. Over an extended and iterative process of work-shopping and system development we developed a human-centered approach built on principles of trust, collaboration and joint ownership for all involved. This approach used a bottom-up ethos designing the system through user-needs, leading to novel technical solutions, which can be seen to directly influence the design insights we contribute here.

Our findings revealed that our musicians formed unexpected and distinct relationships with the creative-AI robot arm (*Jess+*). They viewed its role in the ensemble differently, but these were nonetheless inclusive. All perceived they were in-the-loop with the system, as they found it to be a good listener with its own creative 'voice'. It was considered non-judgmental and accepting, which promoted a new freedom of expression and comfort in taking musical risks when improvising. Jess, as hoped, viewed the system as an additional layer of creativity and felt empowered by its inclusive potential. Whereas Clare and Deirdre elevated the system beyond a tool to stimulate musical ideas to one of it being a 'creative accompanist'. Our findings contribute to matters of human-AI co-creation and collaboration in artistic settings, the potential of such tools in flattening hierarchy's and promoting inclusivity, and some supporting design recommendations for their implementation.

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